Section 3

EO-1 Mission Overview & Status

. . . Nicholas Speciale

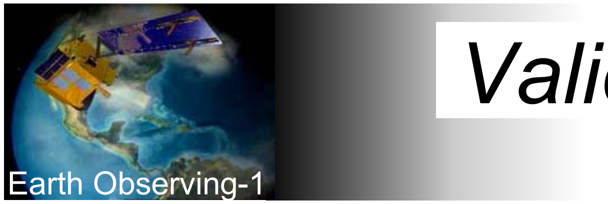
Earth Observing-1 Mission Technologist

What is EO-1?

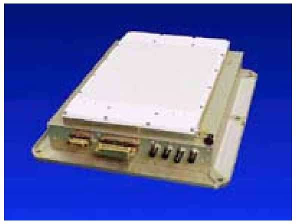
Visit our
Web Site @

http://eo1.gsfc.nasa.gov/

- ***Designed to flight validate breakthrough technologies applicable to Landsat follow-on missions***
- ***Specifically responsive to the Land Remote Sensing Policy Act of 1992 (Public Law 102-55) wherein NASA is charged to ensure Landsat data continuity through the use of advanced technology:***
  - ***Multispectral Imaging capability to address traditional Landsat user community***
  - ***Hyperspectral Imaging capability to address Landsat research-oriented community -- backward compatibility essential***
  - ***Calibration test bed to improve absolute radiometric accuracy***
  - ***Atmospheric correction to compensate for intervening atmosphere***



Validation of Breakthrough Technologies



X-Band Phased Array Antenna:

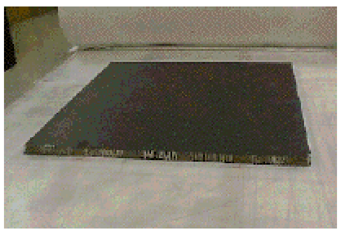
Boeing, GSFC & Lewis Research Center

Leisa Atmospheric Corrector:

GSFC

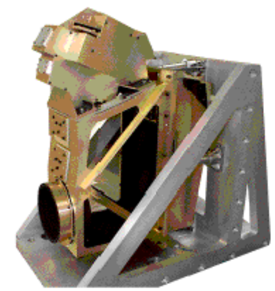
Advanced Land Imager:

MIT Lincoln Lab, GSFC, Raytheon / Santa Barbara Remote Sensing, & Sensor Systems Group



Carbon-Carbon Radiator:

Air Force Research Lab, Amoco Polymers, BF Goodrich, GSFC, Langley Research Center,
Lockheed Martin, Naval Surface Warfare Center, & TRW



Hyperion:

TRW, JPL, GSFC

Wideband Advanced Recorder Processor:

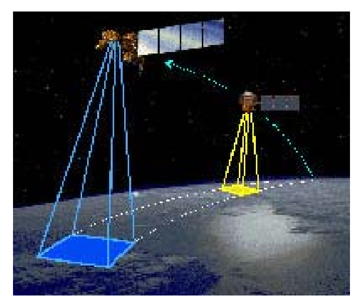
GSFC, Litton,
MIT Lincoln Lab,
Swales, & TRW

Lightweight Flexible Solar Array:

GSFC,
Lockheed Martin,
& Phillips Lab

Pulsed Plasma Thruster:

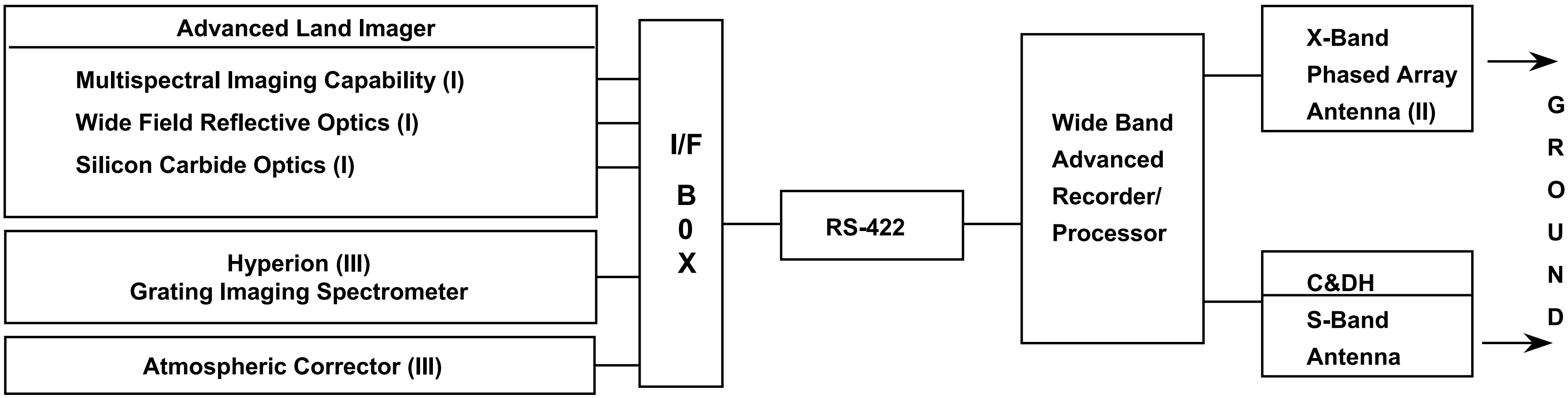
GSFC,
Lewis Research Center & PRIMEX

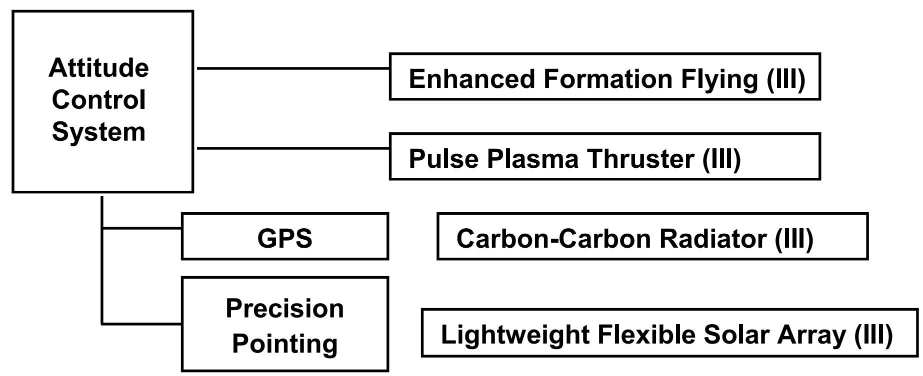


Enhanced Formation Flying

GSFC, JPL

EO-1 Technologies

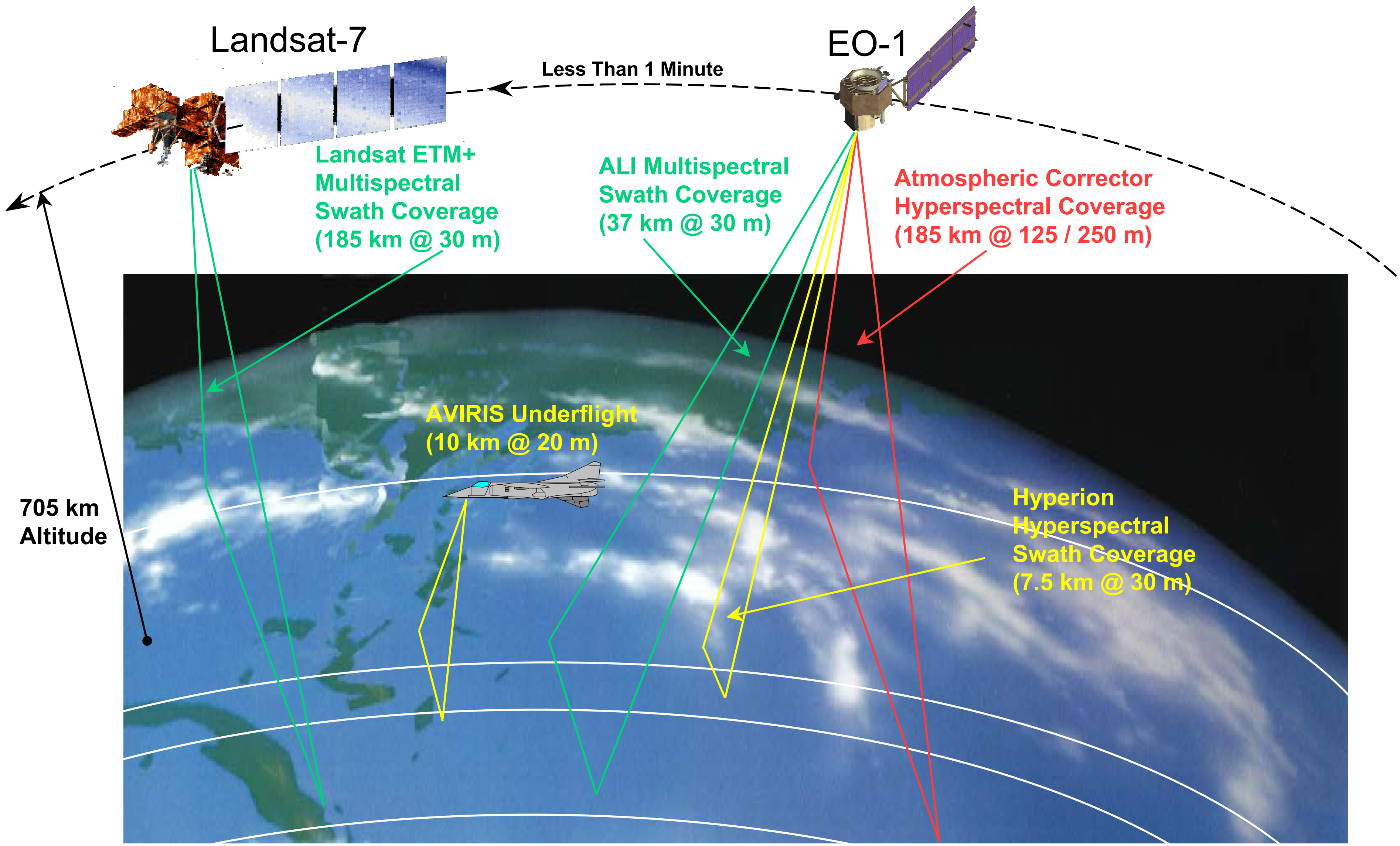




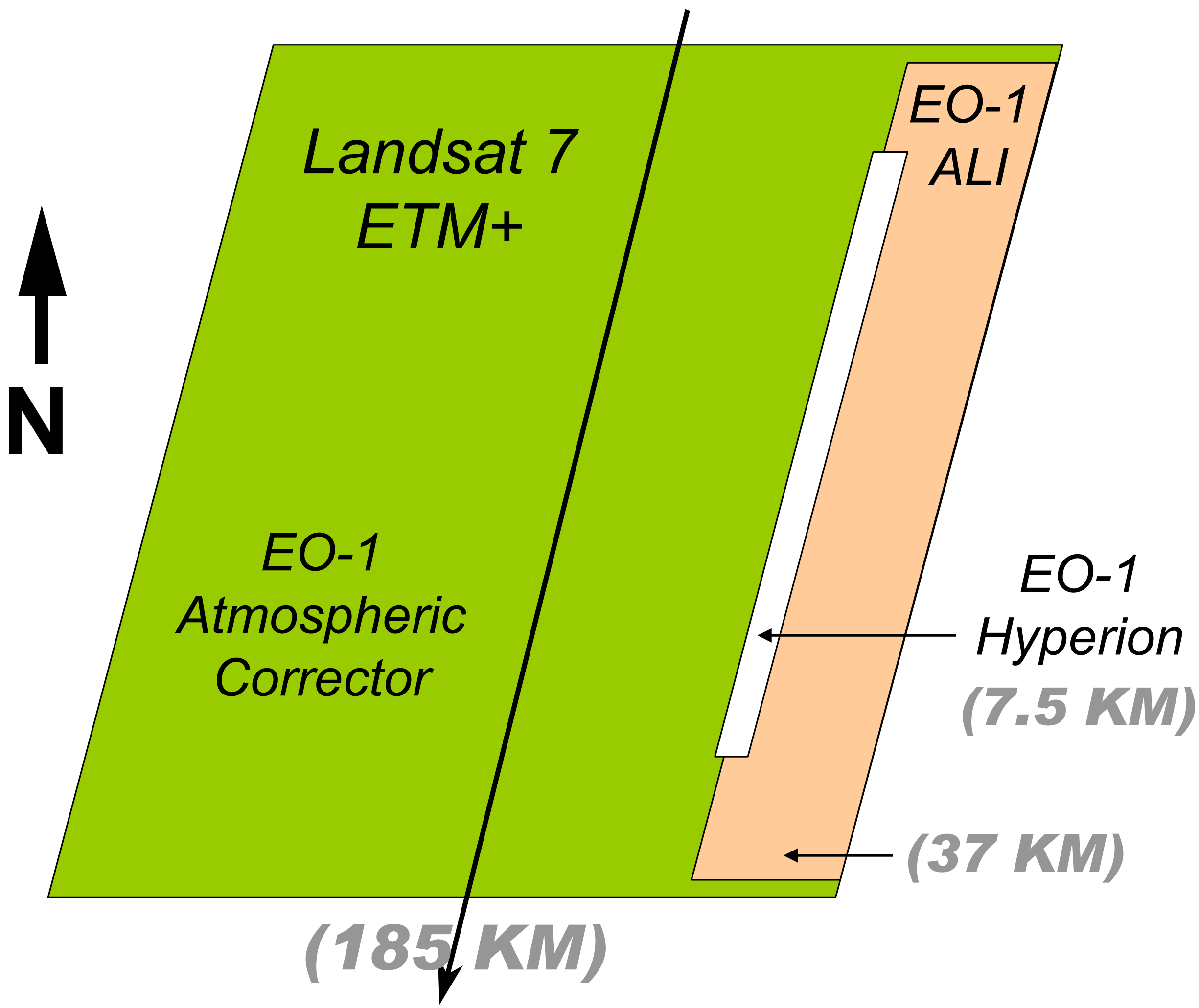
EO-1 TECHNOLOGIES

- *Multispectral Imaging Capability*
- *Wide Field Reflective Optics*
- *Silicon Carbide Optics*
- *Grating Imaging Spectrometer (HYPERION)*
- *Atmospheric Corrector (AC)*
- *X-Band Phased Array Antenna*
- *Enhanced Formation Flying (EFF)*
- *Pulse Plasma Thruster (PPT)*
- *Carbon-Carbon Radiator (CCR)*
- *Lightweight Flexible Solar Array*
- *Wideband Advanced Recorder / Processor (WARP)*

EO-1 & Landsat

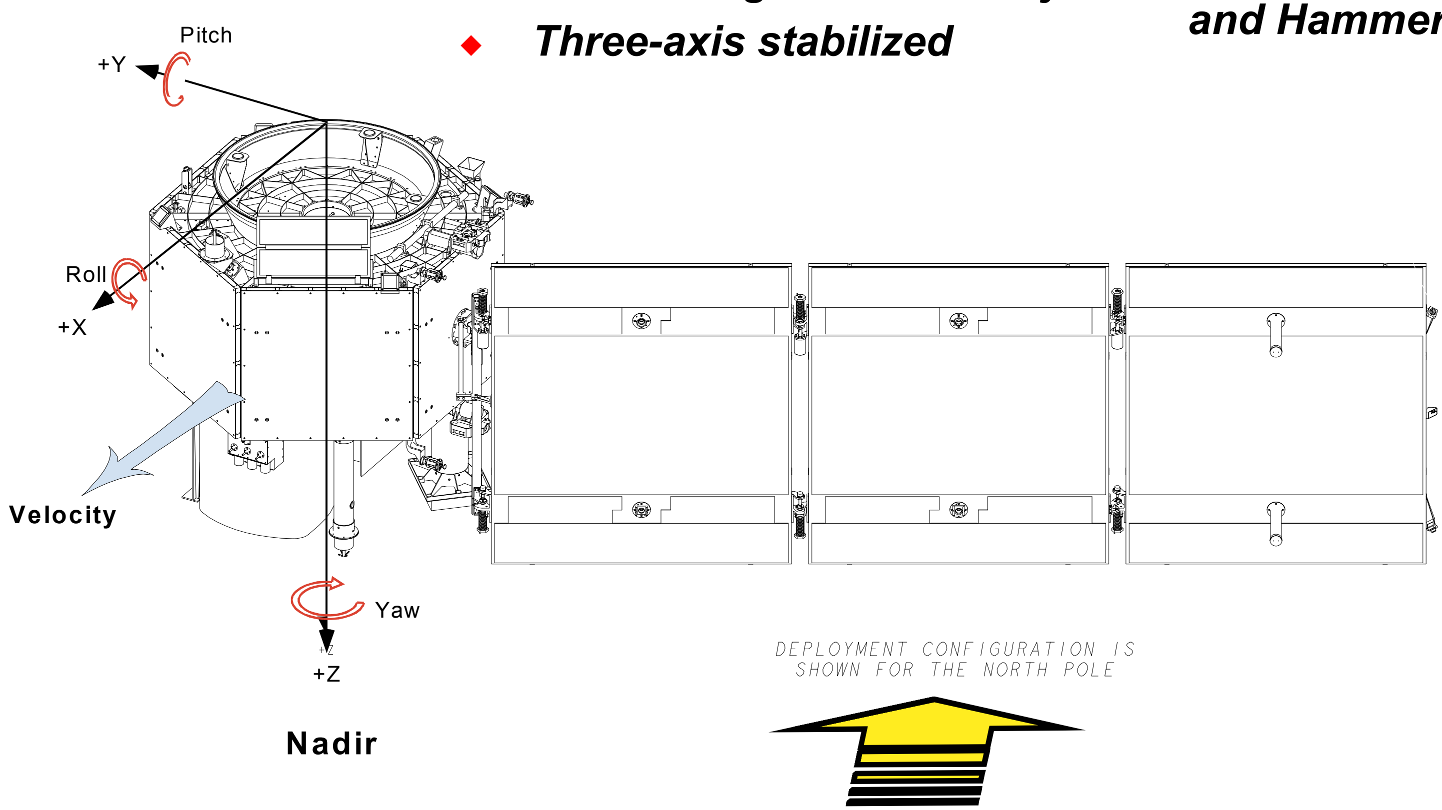

Landsat-7
EO-1
Less Than 1 Minute
Landsat ETM+ Multispectral Swath Coverage (185 km @ 30 m)
ALI Multispectral Swath Coverage (37 km @ 30 m)
Atmospheric Corrector Hyperspectral Coverage (185 km @ 125 / 250 m)
AVIRIS Underflight (10 km @ 20 m)
705 km Altitude
Hyperion Hyperspectral Swath Coverage (7.5 km @ 30 m)

EO-1 & Landsat-7 Descending Orbit Ground Tracks

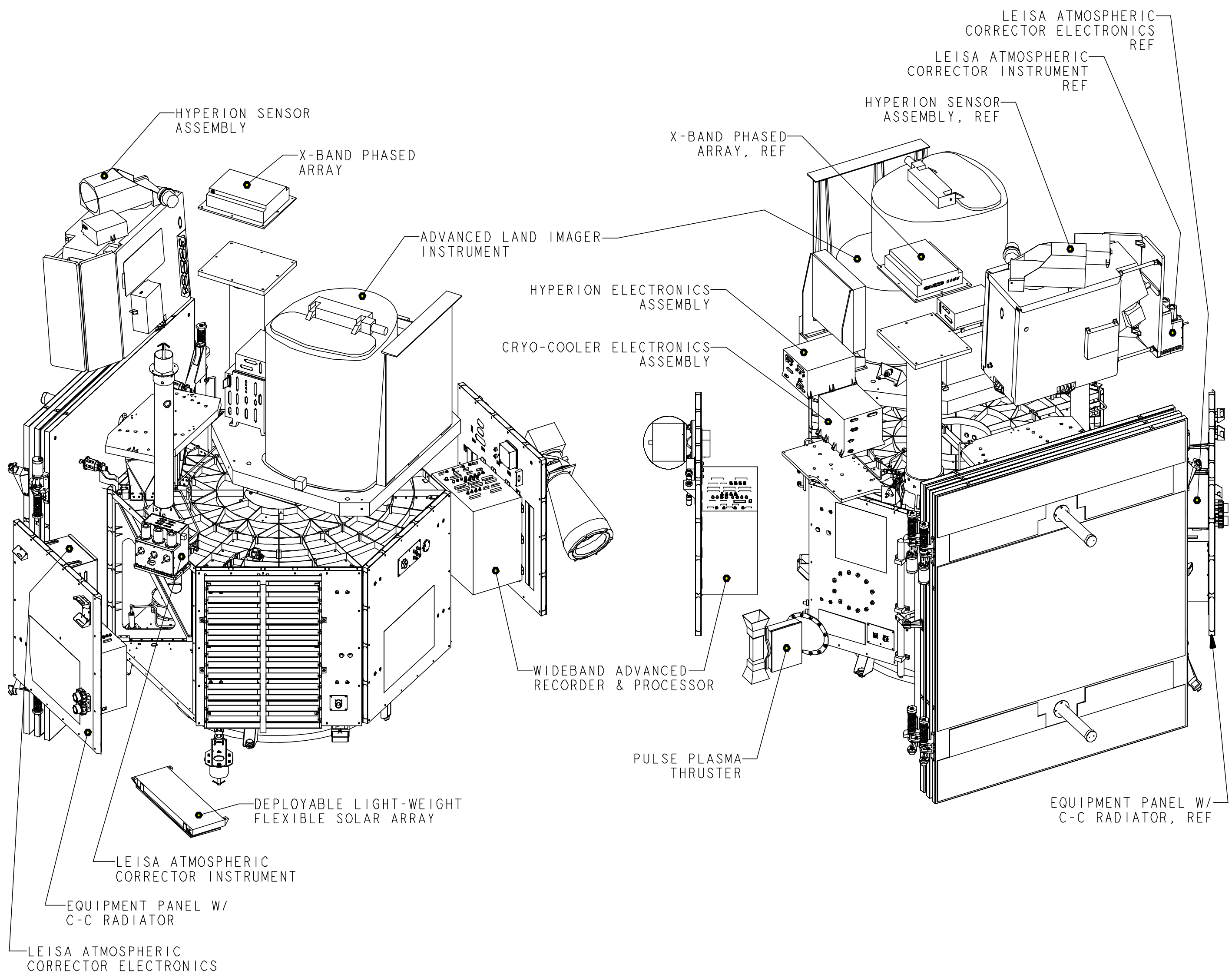


EO-1 Spacecraft

- ***Power***
  - *315 Watts*
  - *50 Ahr*
  - *Super NiCd*
- ***Data Storage***
  - *Housekeeping: 1 Gbit*
  - *Science: 48 Gbits*
- ***Articulating Si Solar Array***
- ***Three-axis stabilized***
- ***Mass***
  - *588 Kg (562.3 Kg actual)*
- ***Built by Swales Aerospace along with Litton Amecom and Hammers Co.***



EO-1 Technology Locations



Mission Characteristics

Mission Design Life: 18 months

Nominal Life: 12 months

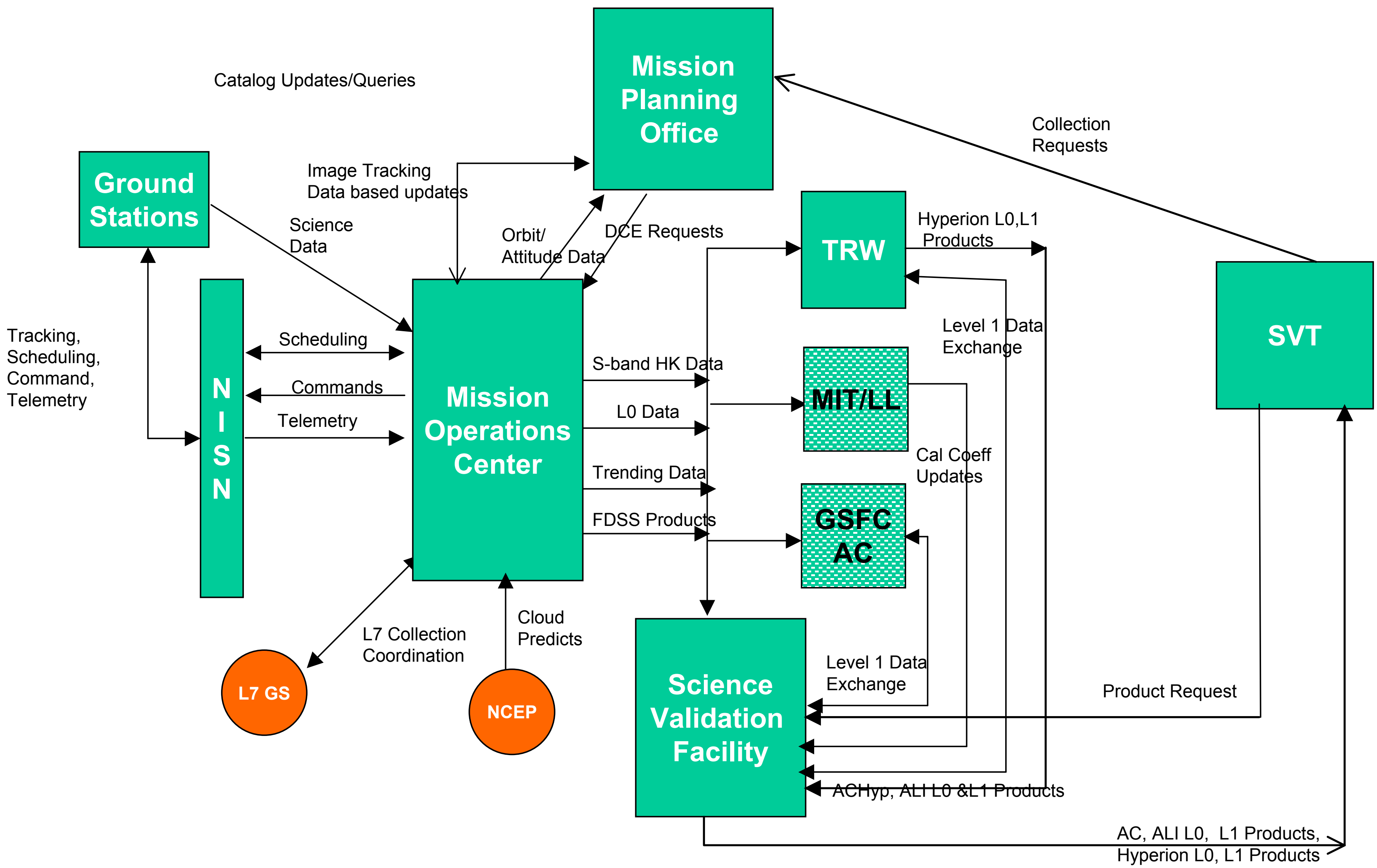
LAUNCH

- **Date:** 11/21/00
- **Time:** 10:24 p.m. PST
- **Window:** 5 seconds
- **Site:** Vandenberg AFB (SLC-2)
- **Launch Vehicle:** Delta II DPAF Mission with SAC-C and 1 secondary payload

ORBIT

- **Equatorial Crossing Time:** 10:03 a.m., descending node
- **Altitude:** 705 Km
- **Inclination:** 98.2°
- **Orbital Period:** 98 minutes

Ground Operations Overview

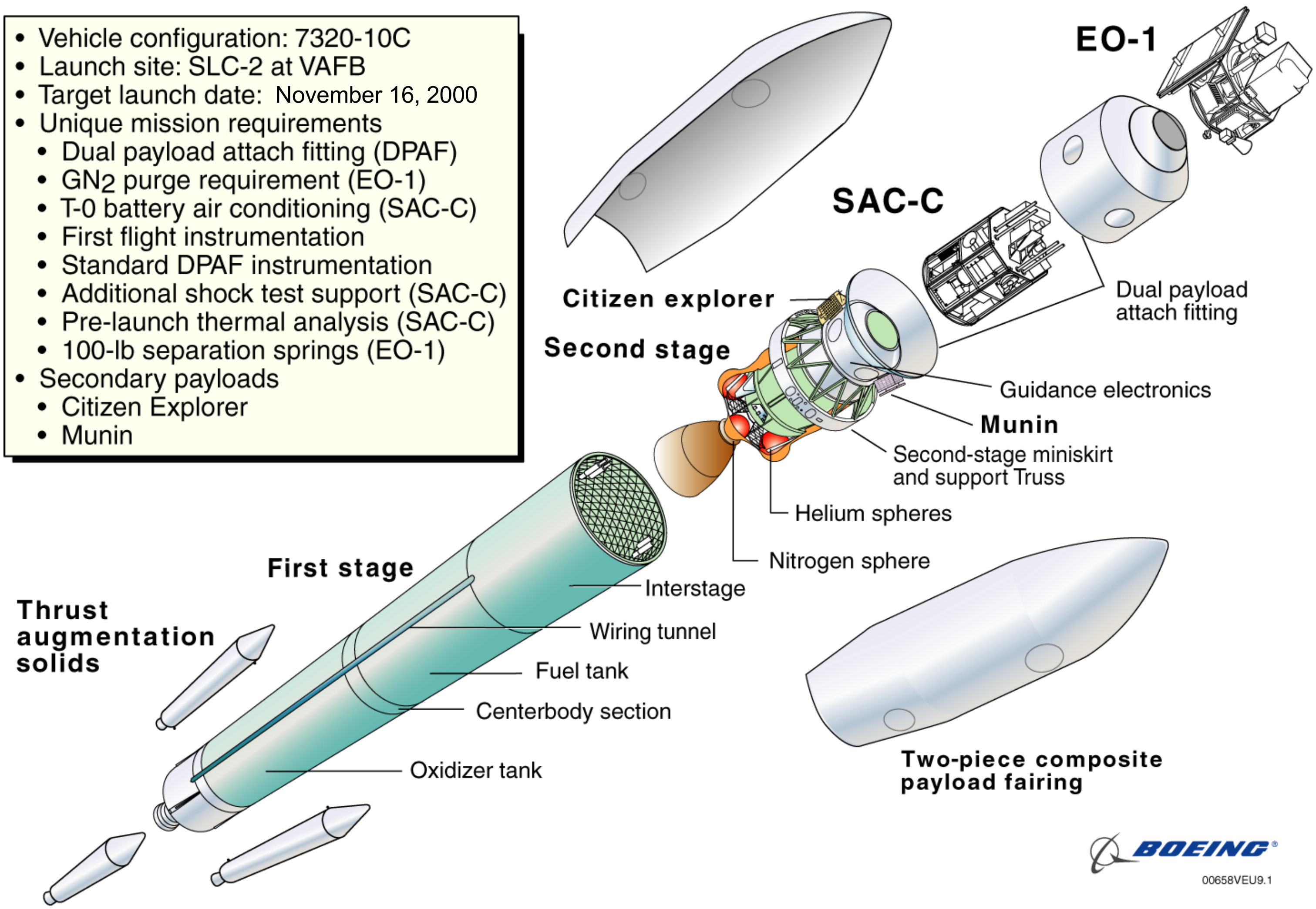


Operations

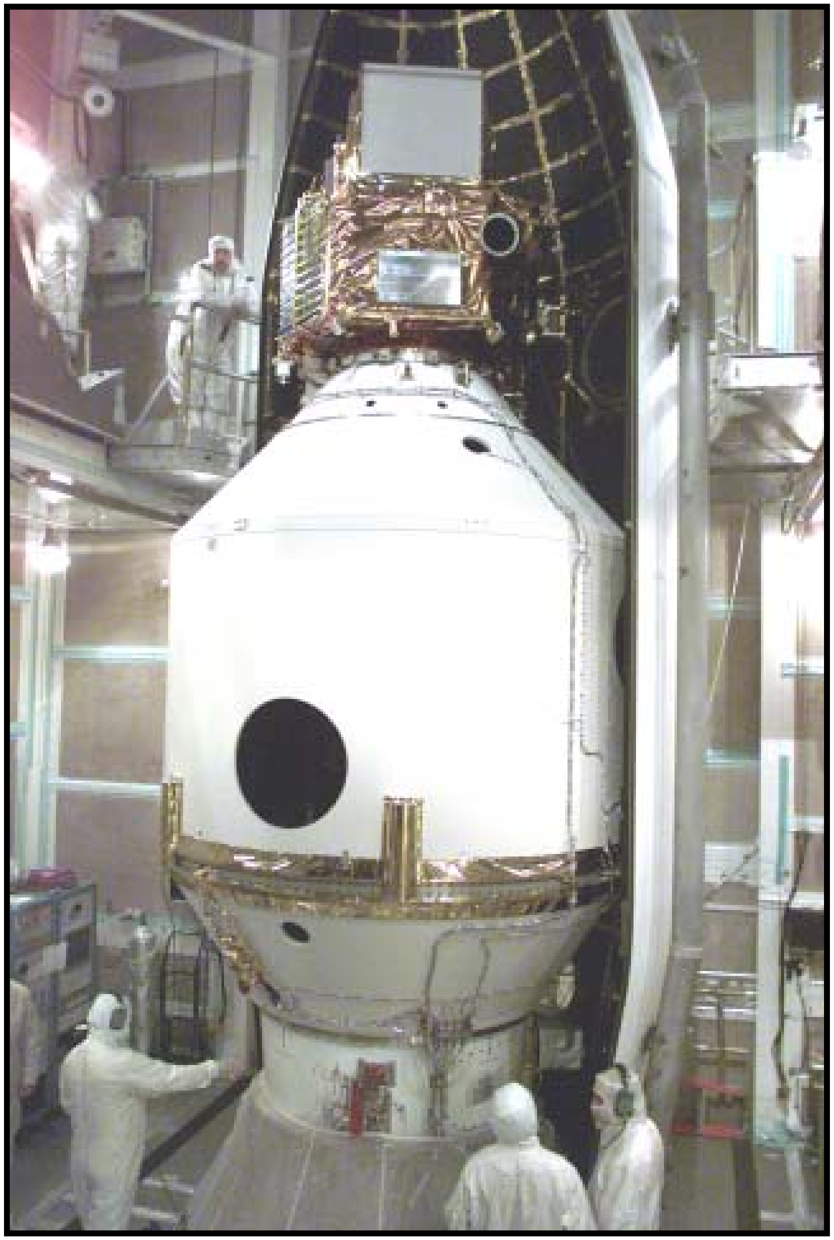
- ***Normal Operations***
  - ***5-7 passes/day (dual S- and X-band) (Norway, Alaska)***
- ***Operations Staffing***
  - ***Currently 24 hr x 7 days/week***
  - ***16hrs x 7days/week beginning September 1, 2001***
- ***Ground stations to receive, process, and route science and housekeeping data to GSFC***
  - ***X-band***
    - *Receive up to 120 Gbits of science data (typically 5-7 Data Collection Events (DCEs) each day) at 105 Mb/s*
    - *Record the received X-band data on hard media, mail to GSFC, and store raw data for 30 days*
  - ***S-band***
    - *Receive data at selected rates up to 2 Mb/s*
    - *Housekeeping data*
      - *Route selected virtual channels to GSFC in real time*
      - *Record up to 200 Mbits of data each day*
      - *FTP recorded data to EO-1 MOC within two hours*
      - *Store raw data for 30 days*
    - *Backup science data (up to 5 Gbits per day): Process as with X-band*

Vehicle Configuration Overview 7320-10C

- Vehicle configuration: 7320-10C
- Launch site: SLC-2 at VAFB
- Target launch date: November 16, 2000
- Unique mission requirements
  - Dual payload attach fitting (DPAF)
  - GN_2 purge requirement (EO-1)
  - T-0 battery air conditioning (SAC-C)
  - First flight instrumentation
  - Standard DPAF instrumentation
  - Additional shock test support (SAC-C)
  - Pre-launch thermal analysis (SAC-C)
  - 100-lb separation springs (EO-1)
- Secondary payloads
  - Citizen Explorer
  - Munin



Spacecraft on DPAF

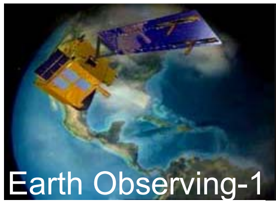


Integrated Spacecraft

Spacecraft on Delta

Advanced Land Imager (ALI)

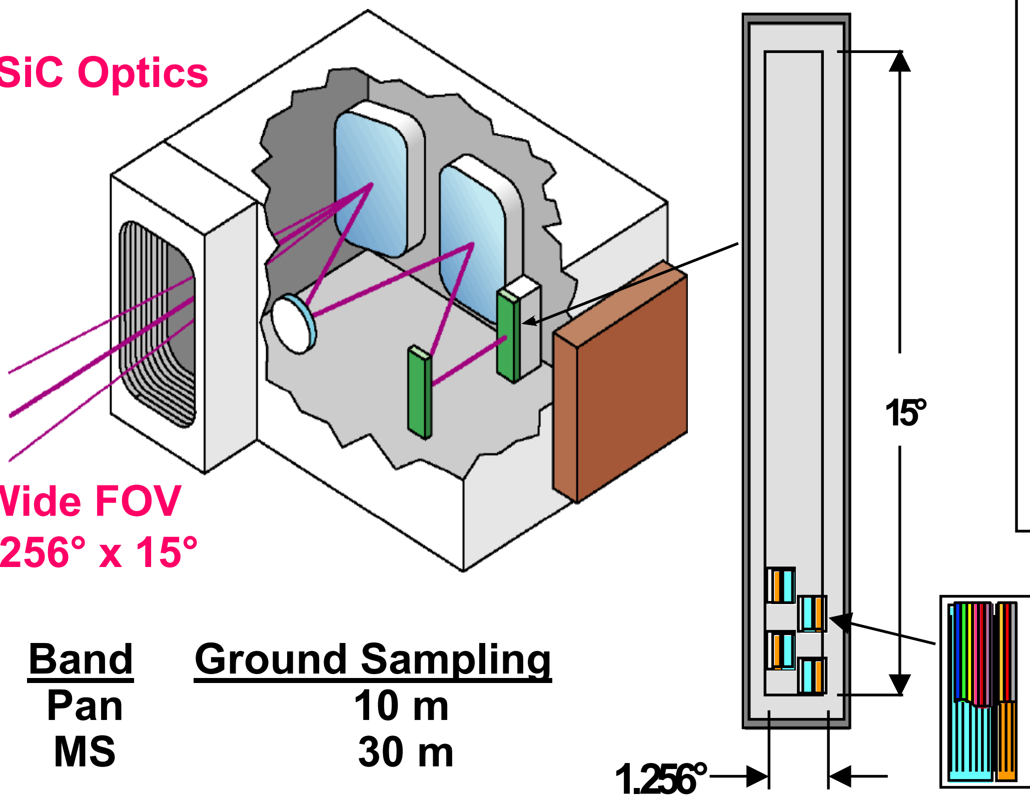
- ***ALI is an instrument incorporating several new technologies that promise better, lower cost performance for future Landsat missions***
  - *The relatively warm operating temperature of the HgCdTe detectors enables passive cooling of the focal plane which greatly simplifies instrument operation*
- ***ALI was designed, assembled, environmentally tested and calibrated by the MIT Lincoln Laboratory***
  - *The Focal Plane System was supplied by Raytheon/ SBRS*
  - *The telescope was supplied by SSG Inc*

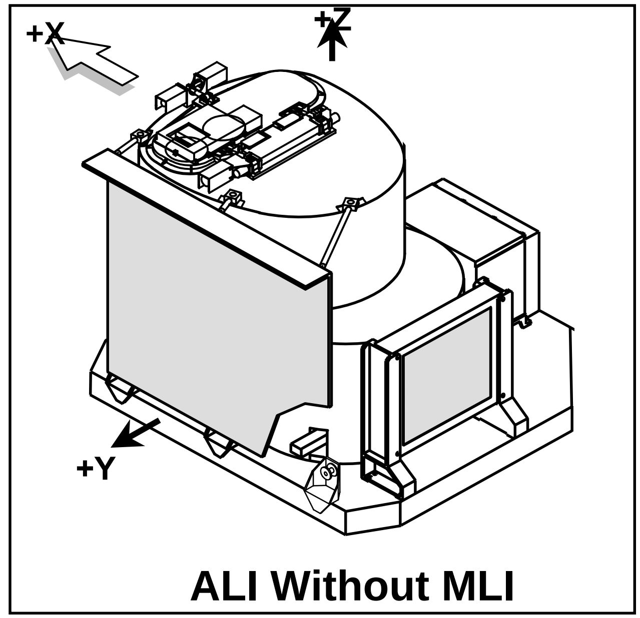


Advanced Land Imager (ALI)

SiC Optics

Main Focal Plane Assembly



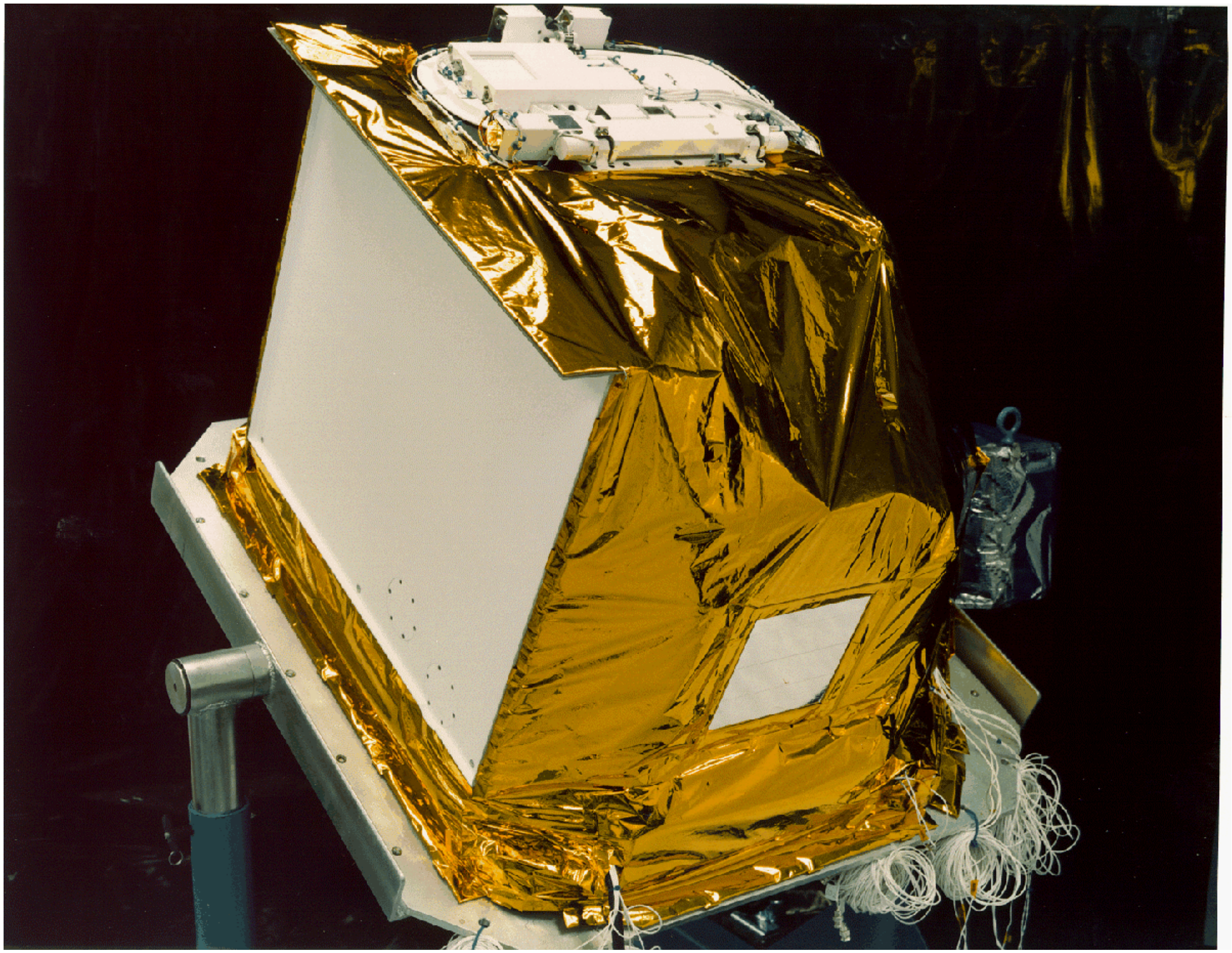


Wide FOV
1.256° x 15°

Band	Ground Sampling
Pan	10 m
MS	30 m

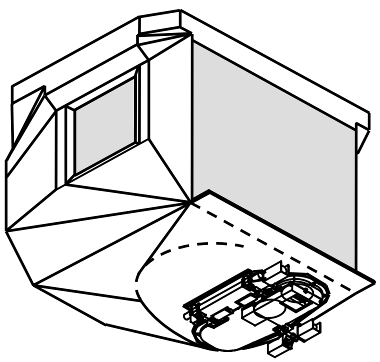
Multispectral/
Panchromatic
6 VNIR + 3 SWIR
220 K

Full Dressed Picture of ALI

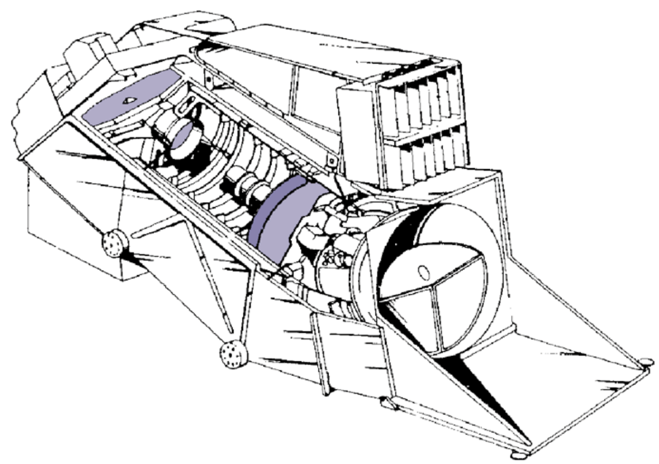


Land Imaging Instrument Comparison

ALI - Concept for Future Landsat Instrument



Enhanced Thematic Mapper (ETM+)



100	**Mass (kg)**	**425**
100	**Power (W)**	**545**
$70 \times 75 \times 75$	**Size (cm)**	**$196 \times 114 \times 66$**
7, 3, 0	**VNIR, SWIR, LWIR Bands**	**5, 2, 1**
10, 30	**Pan, MS Resolution (m)**	**15, 30**
4-10	**Relative SNR**	**1**

Mt. Etna (July 23, 2001)

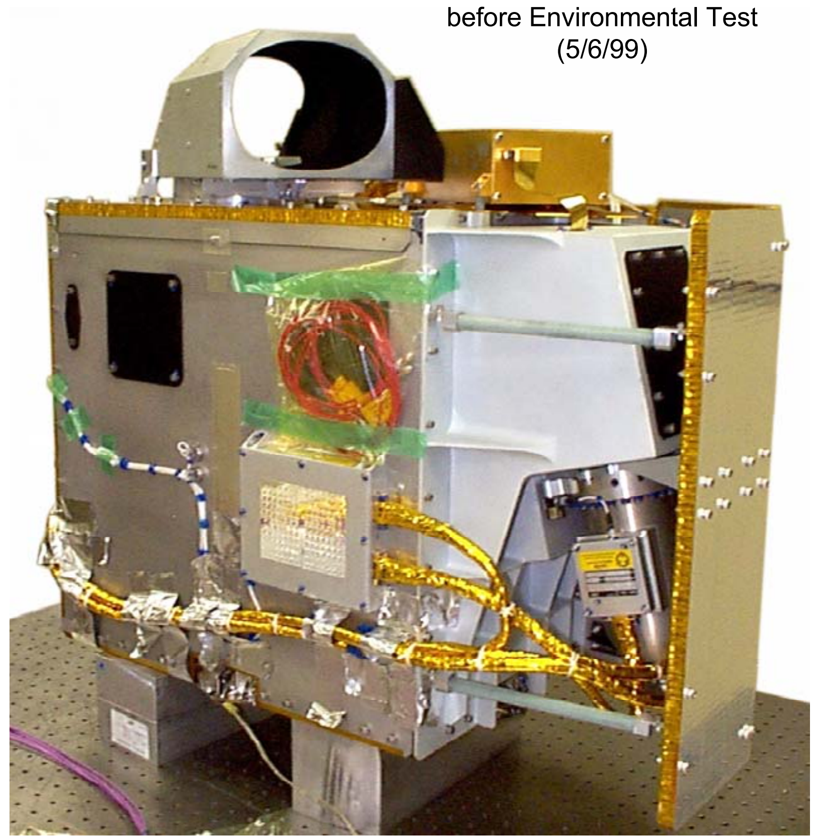
Hyperion

- ***The Hyperion instrument on EO-1 is the first hyperspectral imager in space, demonstrating this new technology***
  - ***Hyperion will set the standard for hyperspectral imagery, enabling NASA to establish minimum requirements for future data buys***
- ***Hyperion FOV is coaligned with ALI's active area to enable cross-calibration of earth scenes with complete spectrum***
  - ***Discrete channels on Landsat and ALI can be checked with Hyperion***
  - ***Comparison with Terra MODIS and ASTER also planned***
- ***Hyperion satisfies NASA's desire to replace the Hyper-Spectral Imager (HSI) that was lost with the Lewis mission.***
  - ***This new technology can provide unique insight into many scientific and commercial disciplines***

Hyperion Hyperspectral Imager

- *Hyperion is a push-broom imager with:*
  - *220 10 nm bands covering the spectrum from 0.4 µm - 2.5 µm*
  - *6% absolute radiometric accuracy*
  - *Image swath width of 7.5 km*
  - *IFOV of 42.5 µrad*
  - *GSD of 30 m at 705 km altitude*
  - *12-bit image data*
  - *MTF 0.34 - 0.48*
  - *Power: 51W orbit avg., 126W peak*
  - *Mass: 49 kg*

Hyperion Sensor Assembly before Environmental Test (5/6/99)

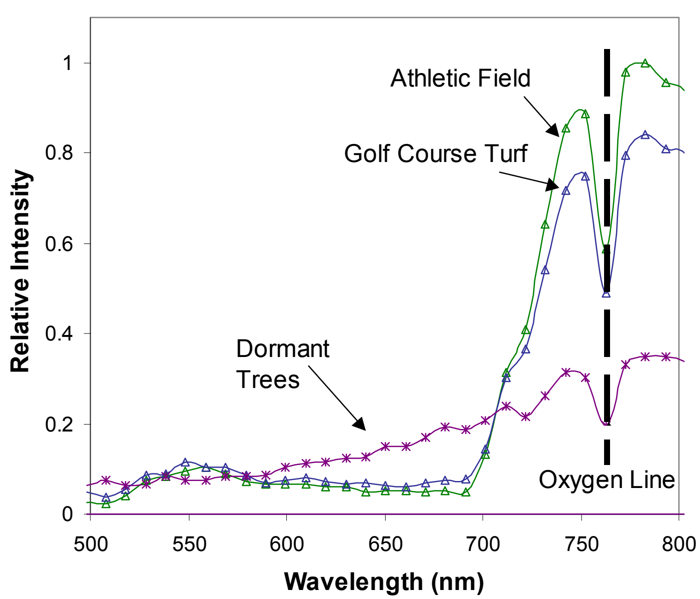


Hyperion
12 months from order to delivery

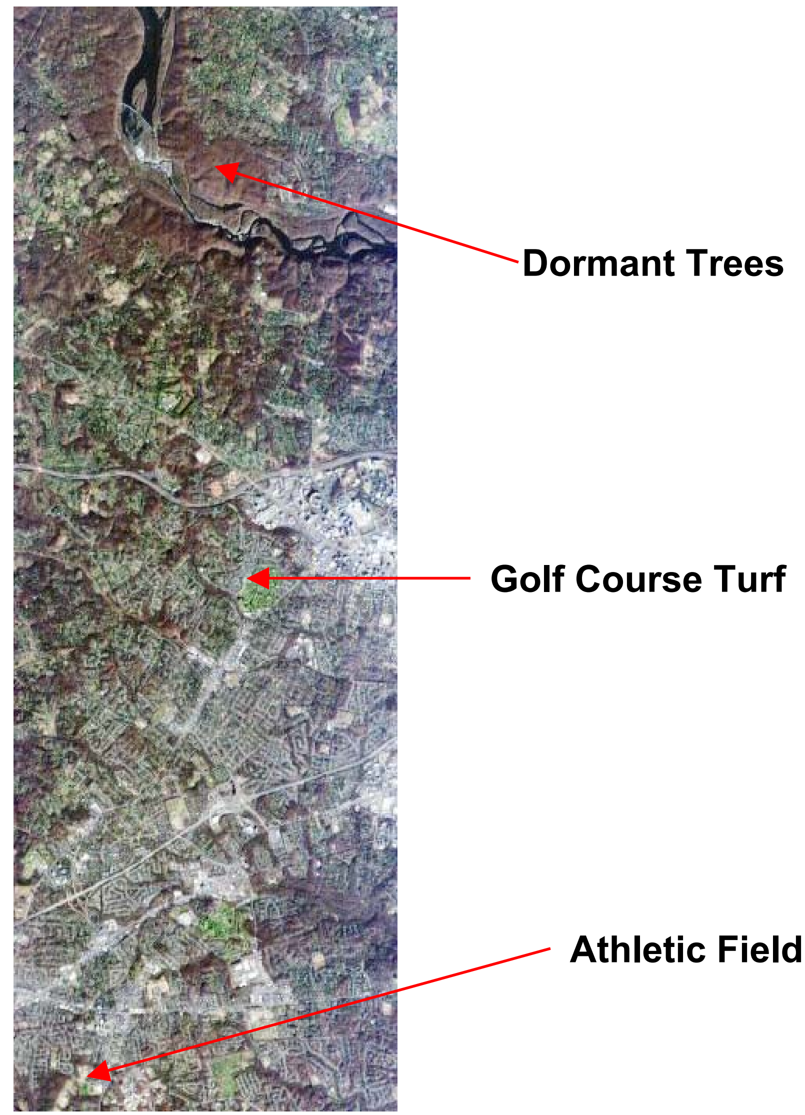
Hyperion Image of Fairfax, VA December 2000

Image taken by Hyperion shows the relative chlorophyll content of vegetation in Fairfax County. The spectral profiles indicate healthy grass in the athletic field and golf course. The spectral profile of the trees indicates dormant vegetation.

Vegetation

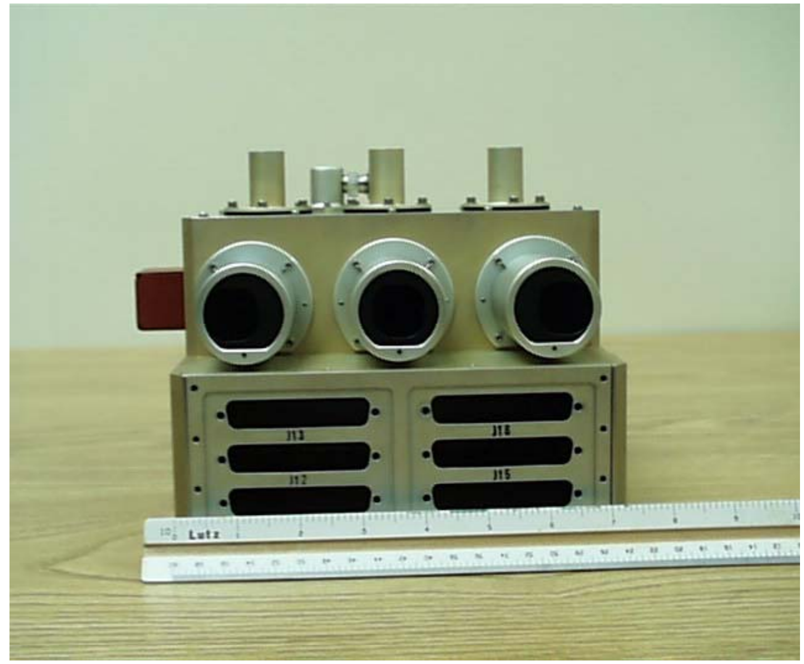


Oxygen in the atmosphere is detected by the spectral profiles in the near infrared wavelength.



LEISA Atmospheric Corrector

- ***Correct High Spatial Resolution Multispectral Imager Data (ALI and Landsat) for Atmospheric Effects on Surface Reflectance.***
  - *In multispectral images, thin cirrus clouds are not distinguishable from surface reflectance effects.*
  - *LAC's high spectral resolution allows differentiation between cirrus clouds and surfaces by looking in water vapor absorption bands. Effects may be removed or data flagged.*



  - *Atmospheric aerosols and water vapor attenuate light reflected from surface, decreasing apparent surface reflectance.*
  - *LAC's spectral measurement capability allows simultaneous retrieval of water vapor amounts and estimation of effect on atmospheric transmittance. This may be divided out of multispectral images to obtain true surface reflectance.*

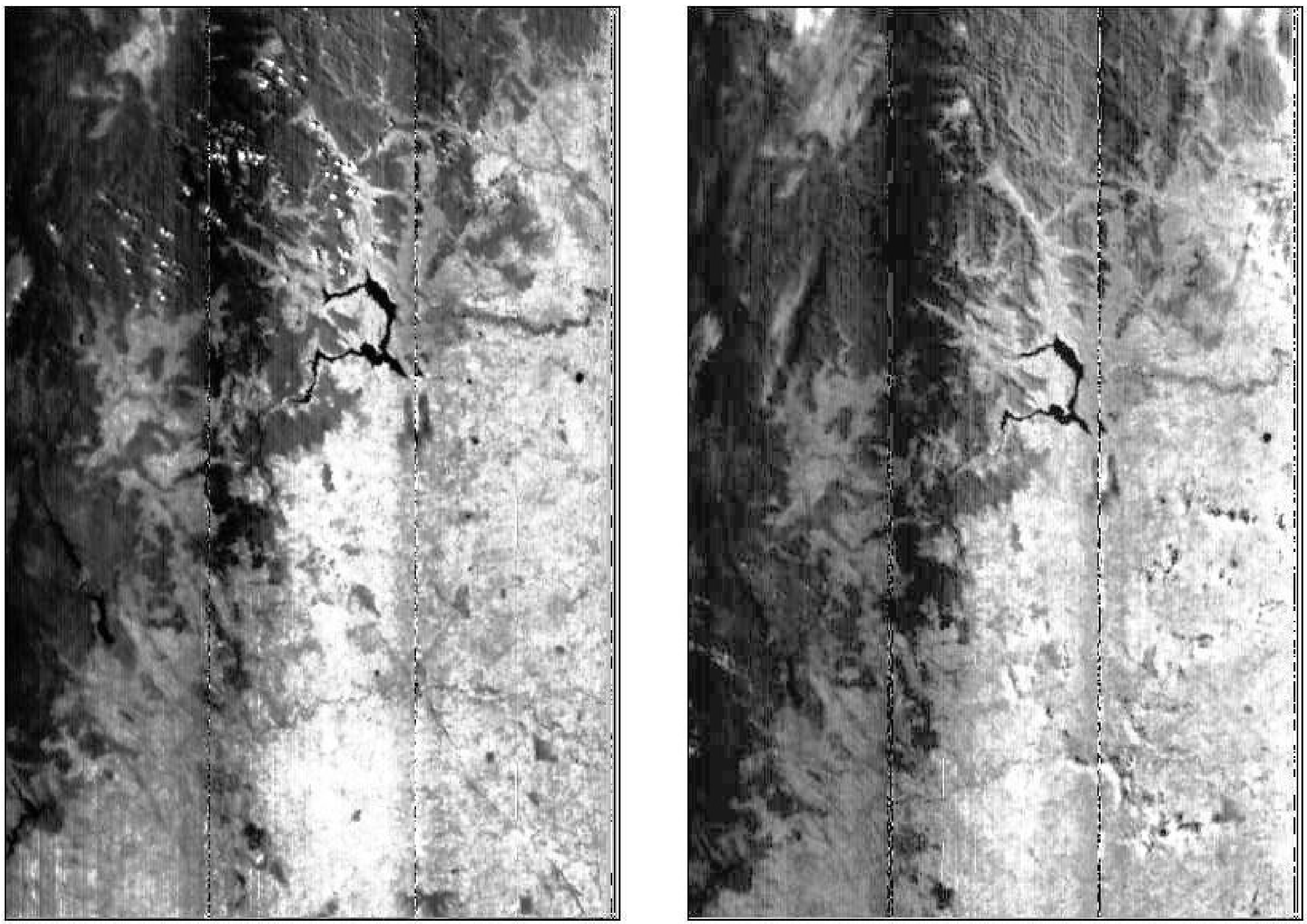
Earth Observing-1

Surface Change Monitoring (e.g Shrinkage of Lakes)

Mission Technology Forum

TUMBARUMBA AUSTRALIA (LAKE HUME in CENTER)

DECEMBER 25 1.26 micron FEBRUARY 12



Tumbarumba (Jupp/N) EO10910852000361111PP *Tumbarumba [Jupp/N] EO10910852001043111PP*

Wideband Advanced Recorder Processor (WARP)

Description:

High Rate (up to 840Mbps capability), high density (48Gbit storage), low weight (less than 25.0 Kg) Solid State Recorder/Processor with X-band modulation capability.

Utilizes advanced integrated circuit packaging (3D stacked memory devices) and “chip on board” bonding techniques to obtain extremely high density memory storage per board (24Gbits/memory card)

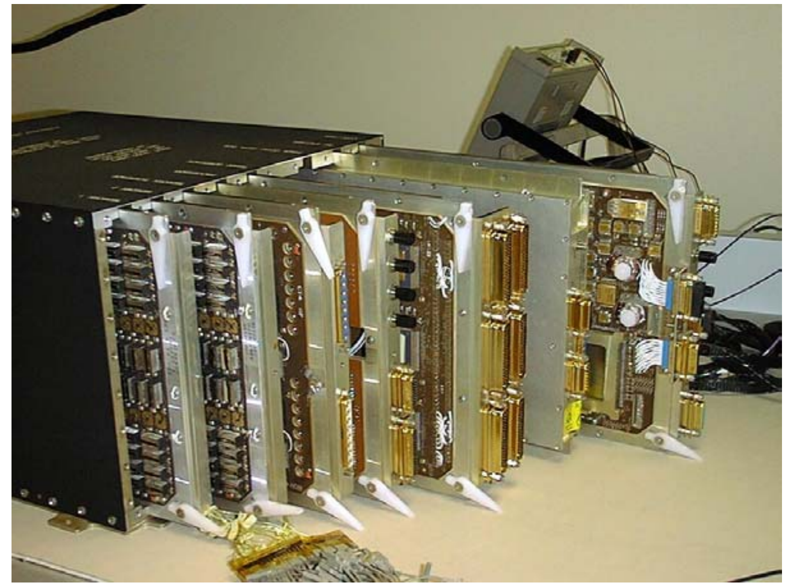
Includes high capacity Mongoose 5 processor which can perform on-orbit data collection, compression and processing of land image scenes.

Validation:

The WARP is required to store and transmit back science image files for the AC, ALI and Hyperion.

Partners:

GSFC and Litton Amecom



Benefits to Future Missions:

The WARP will validate a number of high density electronic board advanced packaging techniques and will provide the highest rate solid state recorder NASA has ever flown.

Its basic architecture and underlying technologies will be required for future earth imaging missions which need to collect, store and process high rate land imaging data.

X-Band Phased Array Antenna (XPAA)

Technology Need:

High rate, reliable RF communication subsystems

Description:

The X-band phased array antenna is composed of a flat grid of 64 radiating elements whose transmitted signals combine spatially to produce desired antenna directivity

– *Avoids problems of deployable structures and moving parts*

– *Lightweight, compact, supports high downlink (100's Mbps) rates.*

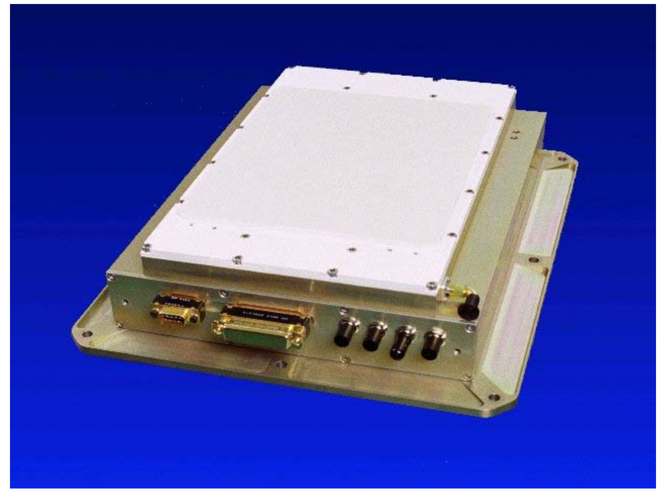
– *Allows simultaneous instrument collection and data downlink.*

Validation:

The XPAA will be validated through measurement of bit error rate performance and effective ground station EIRP during science data downlinks over the lifetime of the mission.

Commercial Partners:

Boeing Phantom Works



Benefits to Future Missions:

Future Earth Science missions will produce tera-bit daily data streams. The Phase Array antenna technology will enable:

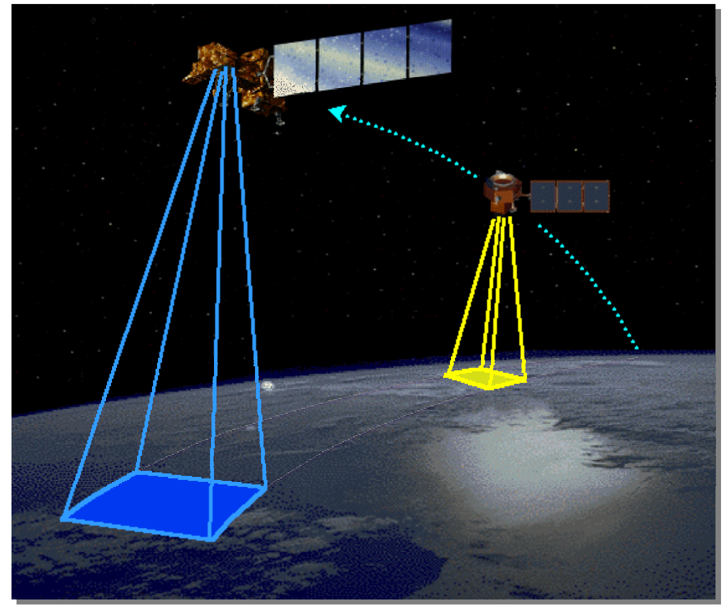
– *Lower cost, weight and higher performance science downlinks*

– *Lower cost and size ground stations*

– *More flexible operations*

Enhanced Formation Flying (EFF)

Maintain separation so that EO-1 follows current Landsat-7 ground track to +/- 3 km



Technology Need:

Constellation Flying

Description:

The enhanced formation flying (EFF) technology features flight software that is capable of autonomously planning, executing, and calibrating routine spacecraft maneuvers to maintain satellites in their respective constellations and formations.

Validation:

Validation of EFF will include demonstrating on-board autonomous capability to fly over Landsat 7 ground track within a +/- 3km while maintaining a one minute separation while an image is collected.

Partners:

JPL,GSFC, Hammers

Benefits to Future Missions:

The EFF technology enables small, inexpensive spacecraft to fly in formation and gather concurrent science data in a “virtual platform.”

This “virtual platform” concept lowers total mission risk, increases science data collection and adds considerable flexibility to future Earth and space science missions.

Pulse Plasma Thruster (PPT)

Technology Need:

Increased payload mass fraction and precision attitude control

Description:

The Pulse Plasma Thruster is a small, self contained electromagnetic propulsion system which uses solid Teflon propellant to deliver high specific impulses (900-1200sec), very low impulse bits (10-1000uN-s) at low power.

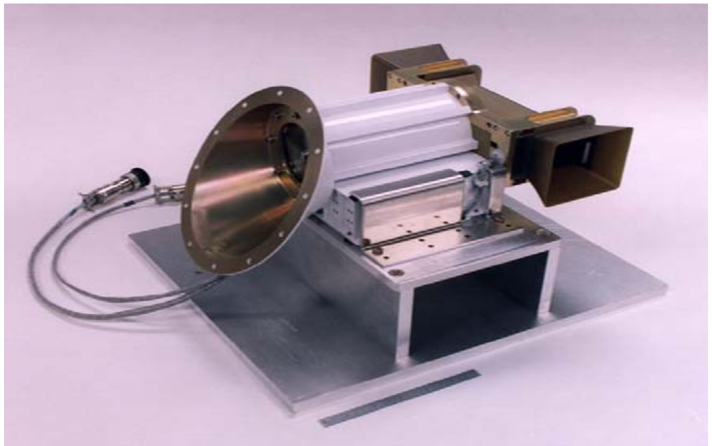
Advantages of this approach include:

- *Ideal candidate for a low mass precision attitude control device.*
- *Replacement of reaction control wheels and other momentum unloading devices. Increase in science payload mass fraction.*

Validation:

The PPT will be substituted (in place of a reaction wheel) during the later phase of the mission. Validation will include:

- *Demonstration of the PPT to provide precision pointing accuracy, response and stability.*
- *Confirmation of benign plume and EMI effects*



Benefits to Future Missions:

The PPT offers new lower mass and cost options for fine precision attitude control for new space or earth science missions

Partners

GRC, Primex, GSFC

Carbon-Carbon Radiator (CCR)

Technology Need:

Increase instrument payload mass fraction.

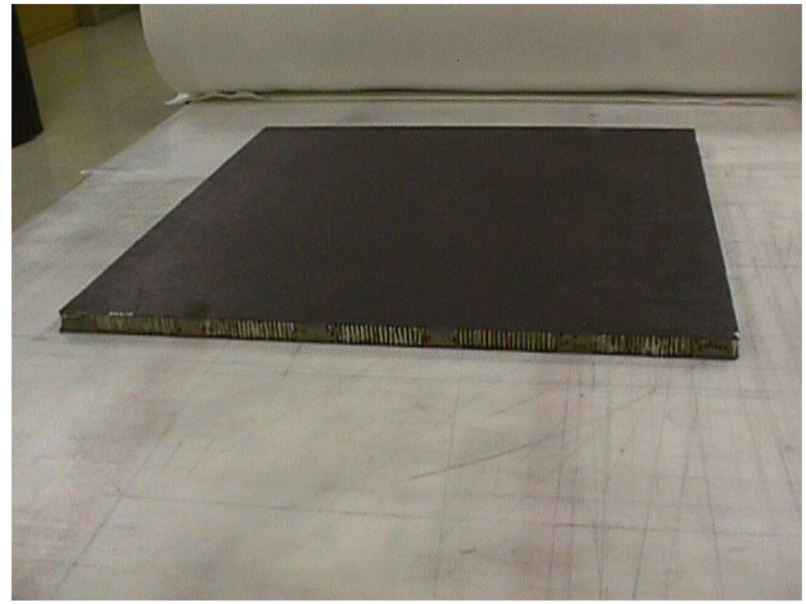
Description:

Carbon-Carbon is a special composite material that uses pure carbon for both the fiber and matrix. The NMP Earth Orbiter – 1 mission will be the first use of this material in a primary structure, serving as both an advanced thermal radiator and a load bearing structure Advantages of Carbon-Carbon include:

- *High thermal conductivity including through thickness*
- *Good strength and weight characteristics*

Validation:

EO-1 will validate the Carbon-Carbon Radiator by replacing one of six aluminum 22” x 27” panels with one constructed using C-C face sheets and an aluminum honeycomb core. Mechanical and thermal properties of the panels will be measured and trended during environmental testing and on-orbit.



Benefits to Future Missions:

This technology offers significant weight reductions over conventional aluminum structures allowing increased science payload mass fractions for Earth Science Missions. Higher thermal conductivity of C-C allows for more space efficient radiator designs.

Partners

CSRP, BF Goodrich

Lightweight Flexible Solar Array (LFSA)

Technology Need:

Increase payload mass fraction.

Description:

The LFSA is a lightweight photovoltaic(PV) solar array which uses thin film Copper Indium Diselenide solar cells and shaped memory hinges for deployment. Chief advantages of this technology are:

– *Greater than 100Watt/kg specific energies compared to conventional Si/GaAs array which average 20-40 Watts/kg.*

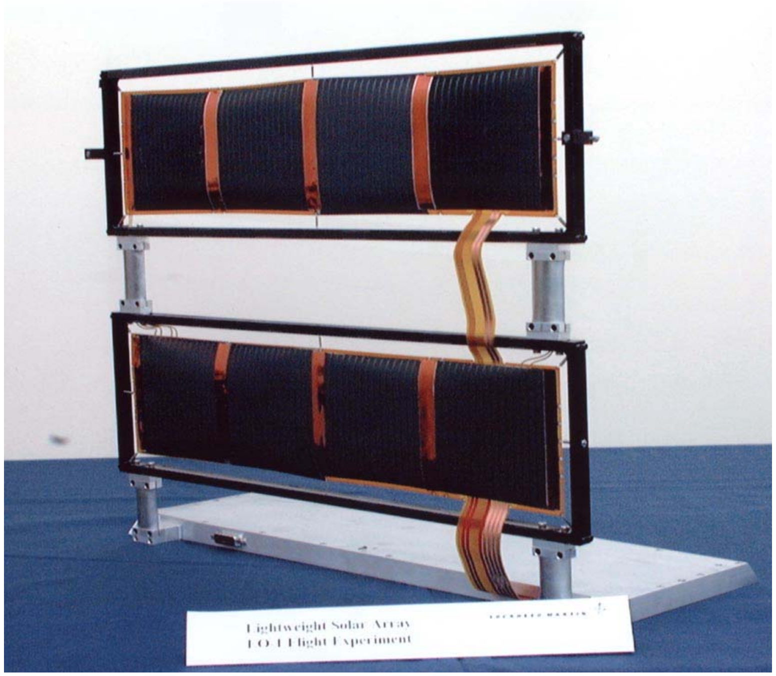
– *Simple shockless deployment mechanism eliminates the need for more complex mechanical solar array deployment systems. Avoids harsh shock to delicate instruments.*

Validation:

The LFSA deployment mechanism and power output will measured on-orbit to determine its ability to withstand long term exposure to radiation, thermal environment and degradation due to exposure to Atomic Oxygen.

Partners

Phillips Lab, Lockheed Martin Corp



Benefits to Future Missions:

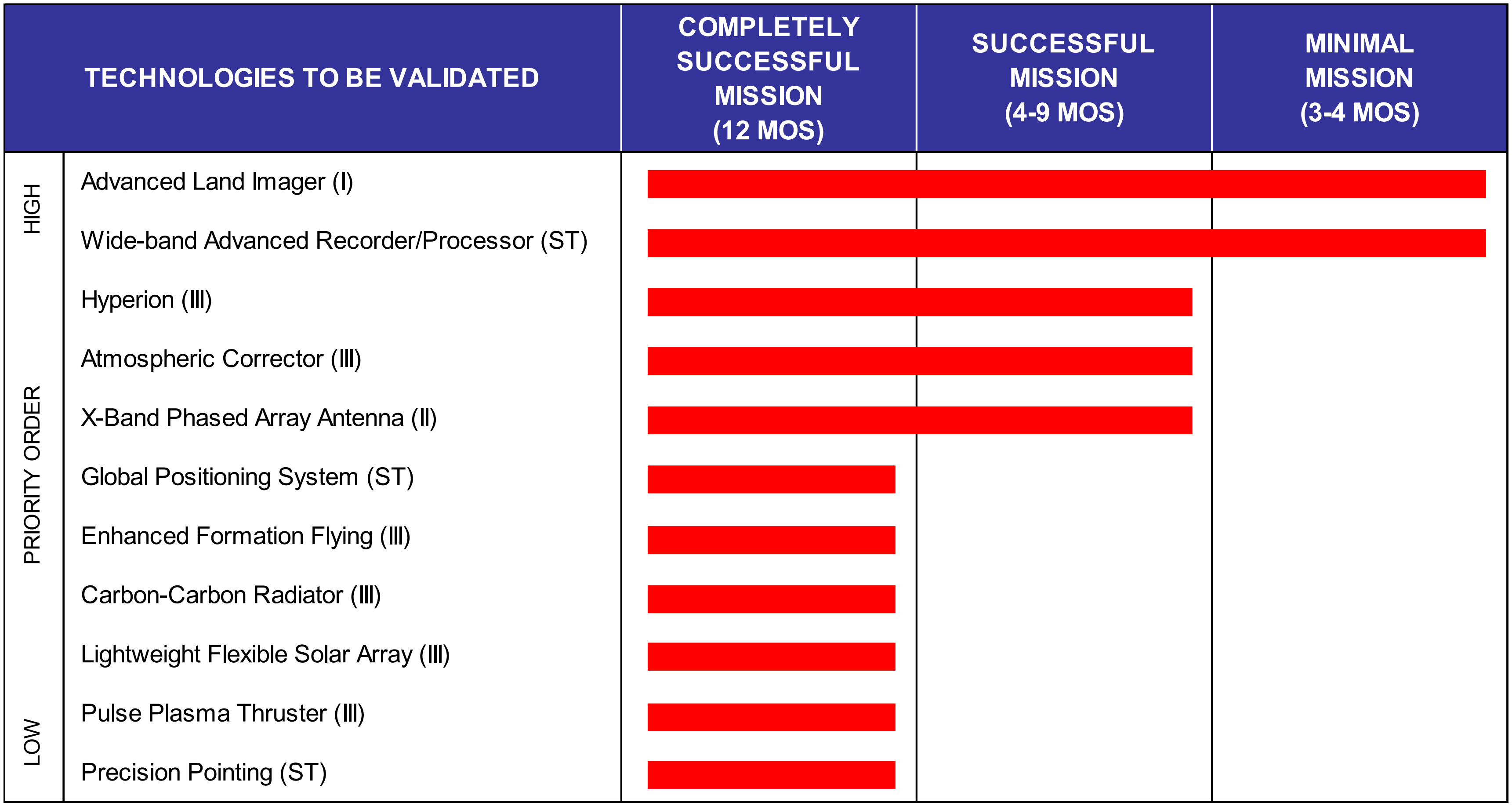
This technology provides much higher power to weight ratios (specific energy) which will enable future missions to increase science payload mass fraction.

Mission Status

- ***EO-1 is operating nominally***
  - ***Spacecraft (S/C) bus operating better than spec***
  - ***No hardware faults to S/C bus, one minor suspected SEU problem effected WARP playbacks for a one week period.***
  - ***No unplanned safeholds or processor restarts (cold or warm)***
  - ***Have maintained formation flying envelope with L7 throughout first 8 months.***
- ***Image collection exceeds original requirement by over 50%***
  - ***Executing 6-7 simultaneous instrument Data Collection Events per day, original requirement was 3-4 per day.***
  - ***Over 1600 DCE scheduled to date, over 95% successfully downlinked and processed to Level 0.***
    - *Includes over 60 special calibration sequences (lunar, deep space, stray light, planetary, solar, night images, star constellations)*

EO-1 Mission Status

Mission Technology Forum



Mission Status

- ***EO-1 has achieved successful mission status (see next chart) and is quickly approaching completely successful mission status. Remaining activities include:***
  - *Complete the EFF-JPL algorithm checkout (end of August)*
  - *Need to flight validate PPT – October timeframe*
  - *Need to complete collection (75% complete to date) of required Science Validation Team DCE's – November 2001*
- ***Technology Validation nearly 90% complete***
- ***Collection of Science Validation in full swing nearly 75% complete***
  - *All scene collections to be completed by November 2001*
  - *Final science validation reports by September 2002*

Technology Validation Scorecard

Technology	Tech Val completed?	Science Val Completed?	Primary Partner	Comment
ALI – MS/Pan	Yes – 6/01	In-progress	Raytheon	Better than spec SNR's
ALI – WFOV	Yes – 6/01	In-progress	MIT/LL	Validated pushbroom technology
ALI – SiC optics	Yes – 8/01	In-progress	SSG	Parallel lab mirror finish program successful
Hyperion	Yes – 6/01	In- progress	TRW	First hyperspectral benchmark
LEISA Atm Corrector (WIS)	Yes – 6/01	In-progress	Rockwell	Minor problems but validated WIS concept
WARP	Yes – 2/01	N/A	GSFC/NG	Over 2500 cycles, one minor problem
LFSA	Yes – 7/01	N/A	Lockheed Martin – Phillips Lab	Problem with CIS/harness interconnects
EFF – GSFC	Yes – 7/01	N/A	GSFC/al solutions	Fully successful
EFF - JPL	No – 8/01	N/A	JPL/ai solutions	In progress
LAII Thermal Coating	Yes – 6/01	N/A		Validated
PPT	No – 10/01	N/A	GRC-Primex	Waiting turn
CCR	Yes – 6/01	N/A	BF-Goodrich	Excellent conductivity
XPAA	Yes – 7/01	N/A	Boeing	Exceeds Requirements

Development & Operations Lessons Learned

- ***Don’t wage a two front war***
- ***Make sure its working in the lab before you commit to flight validating it (TRL 6 minimum)***
- ***Avoid nested technologies – architecture is critical***
- ***Maintain higher budgetary reserves for technology validation missions.***
- ***Project and system engineering teams and tools were insufficient from start of project***
- ***Maintain sufficient level of reviews, documentation, configuration management and QA controls.***
- ***Keep an eye on the easy stuff***
- ***Validate as you will operate the target mission***
- ***Don’t bypass Engineering Test Units***
- ***Risk Management and Mitigation***

Summary

- ***EO-1 is doing great and validating key technologies for future missions.***
  - *Technology Validation nearly complete*
  - *Science Validation well underway*
- ***ALI is proving itself as pathfinder for next generation of Landsat imagers***
- ***Hyperion and LAC first Hyperspectral instruments for remote sensing applications***
  - *Establishing baseline performance for next generation of imagers*
- ***Other S/C technologies have excellent potential for infusion into future earth and space science and commercial missions***

Credits

Many thanks to the NASA Team and EO-1 Partners for their dedication, talent, and excellence in support of the successful NMP EO-1 mission

- ***Massachusetts Institute of Technology, Lincoln Laboratory***
- ***SSG Precision Optronics, Inc.***
- ***Raytheon***
- ***TRW Space & Technology***
- ***Swales Aerospace, Inc.***
- ***Lockheed Martin***
- ***NASA Jet Propulsion Laboratory***
- ***Boeing***
- ***CSRP***
- ***General Dynamics (Primex)***
- ***Glenn Research Center***
- ***Litton Amecom (Northrop Grumman)***
- ***AI Solutions***
- ***Hammers and Associates***
- ***Honeywell***